NIST Combinatorial Methods Center
Kick-Off Meeting
Wednesday, January 23, 2002

High-Throughput Screening of Molecular Transport and Diffusion through Films, Membranes, and Nanostructures

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Outline

- Brief Overview of Membrane Science Program
- Membrane Characterization
- Transport Data Compilation
- High-Throughput Screening Project
- Control system
- Detection system
- Molecular probe development
- Data Analysis including Q.S.P.R. development
- Alternatives measurement systems under consideration
- Transport Standardization

Membrane Science Program Overview

- Liquid-liquid porosimetry project
- ATR-FTIR membrane transport project
- Membrane test cell, standard membrane fouling solution development
- Field-Flow Fractionation for membrane transport properties analysis
- Membrane transport properties database development (membranes.nist.gov)
- High-throughput transport properties measurement system
- Standard membrane development

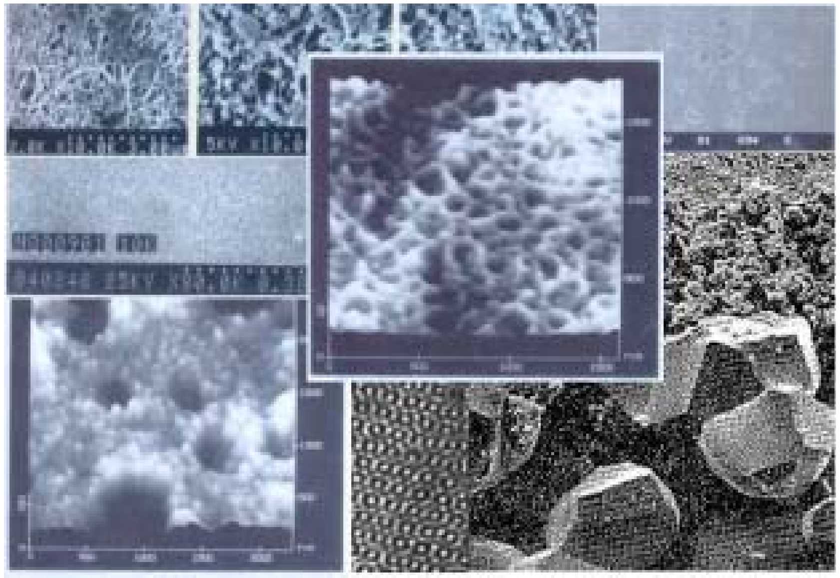
Motivation for H.T.E. Membrane Project

Whether the scale is 1-5 nm (small molecules and macromolecules), or 1000's of nm (fine particles and colloids), …

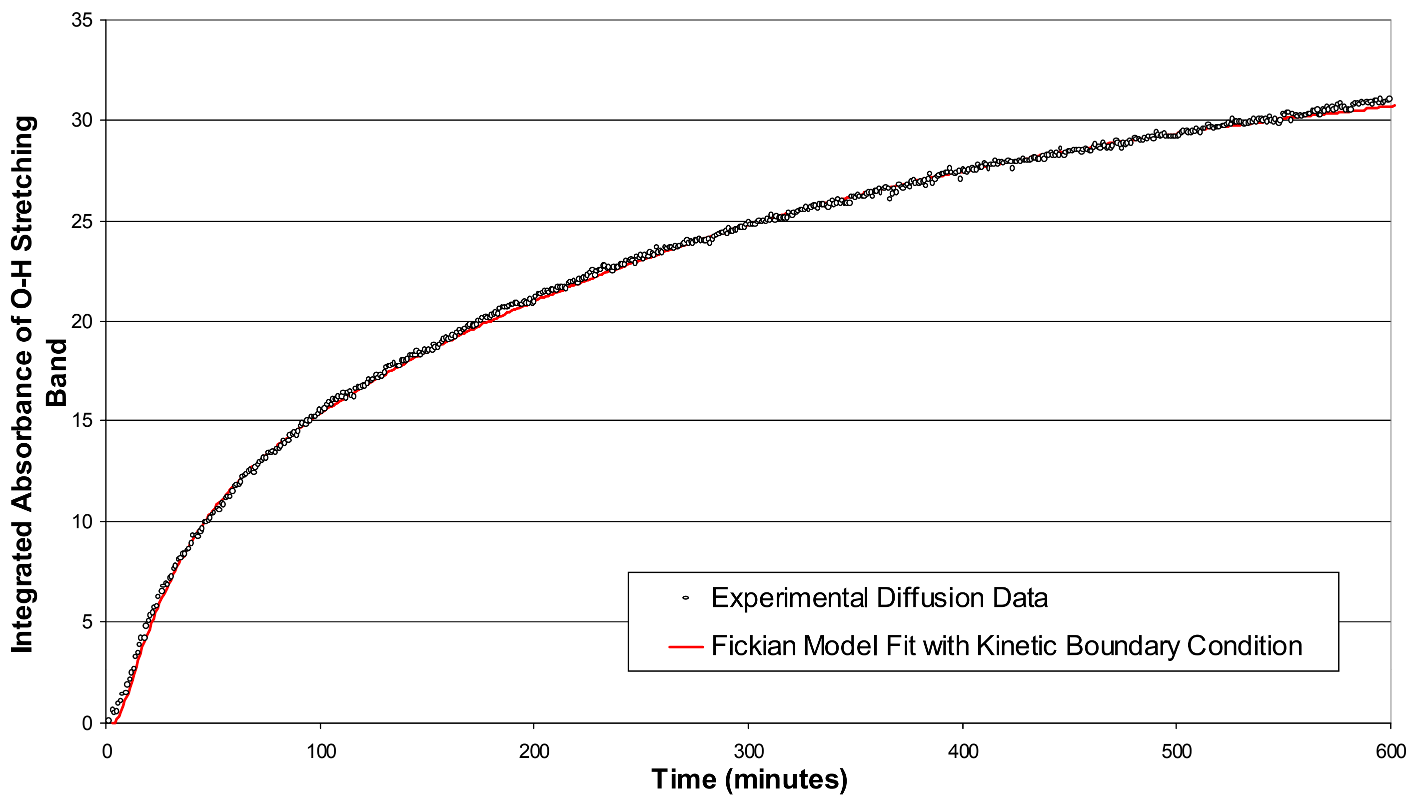
The transport rate is governed by how much gets into the film and how fast it moves, a solubility and a diffusivity

This viewpoint is just as valid whether one is causing hydrodynamic pressure-driven transport or strictly activity-driven permeation.

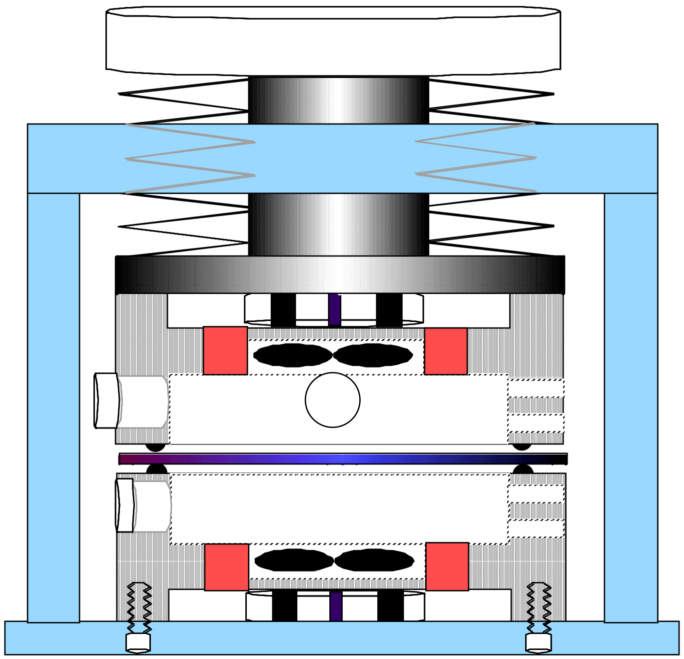
The transport parameters are influenced by both physical and chemical properties of the mixtures and the film's material structure.

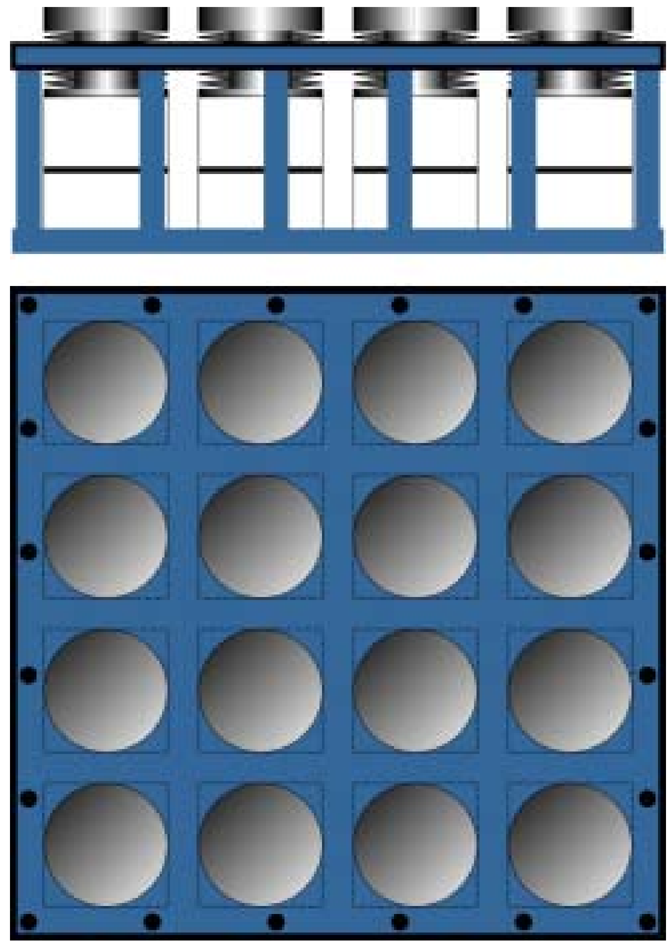


Water Diffusion in 60μm Treated Polypropylene Film



Rapid Transport Measuring System





Strategy

Parallel development of

• a multicell control system that is scalable to as many as 144 cells.

• a single transport cell capable of measuring the transport of a wide variety of test compounds.

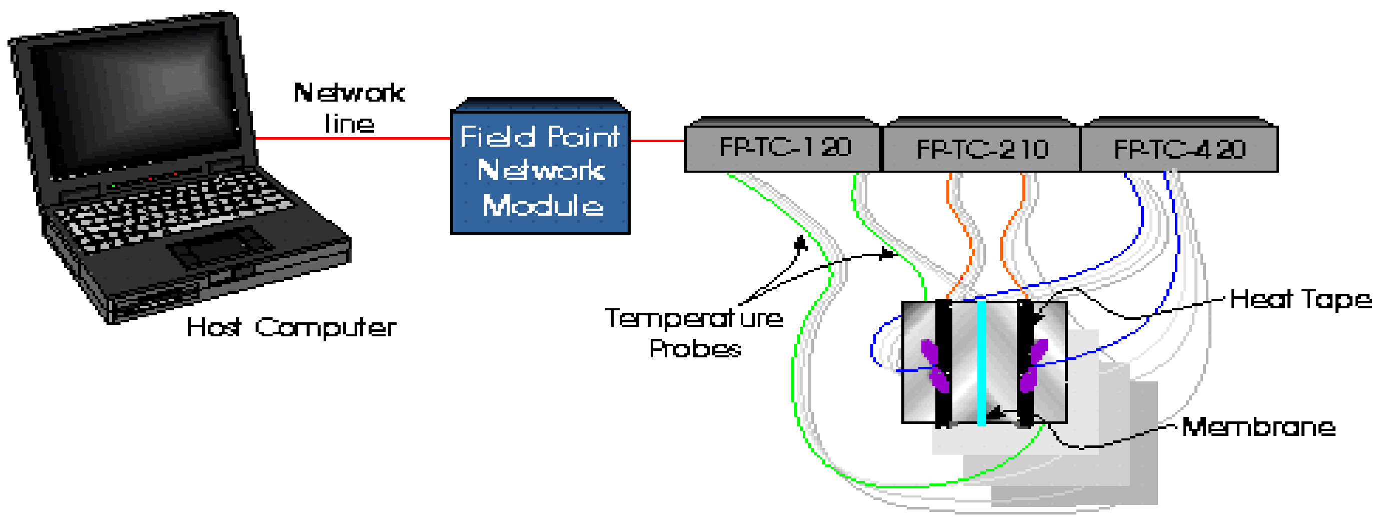
• a detection system that is capable of seeing trace quantities of a wide range of probe molecules.

• a test fluid delivery system.

• a set of probe molecules that will probe sizes in a range from 1-500 nm along with various chemical properties.

• a set of quantitative structure property relationships along with computer models for correlating these with data.

Control System



Detection System

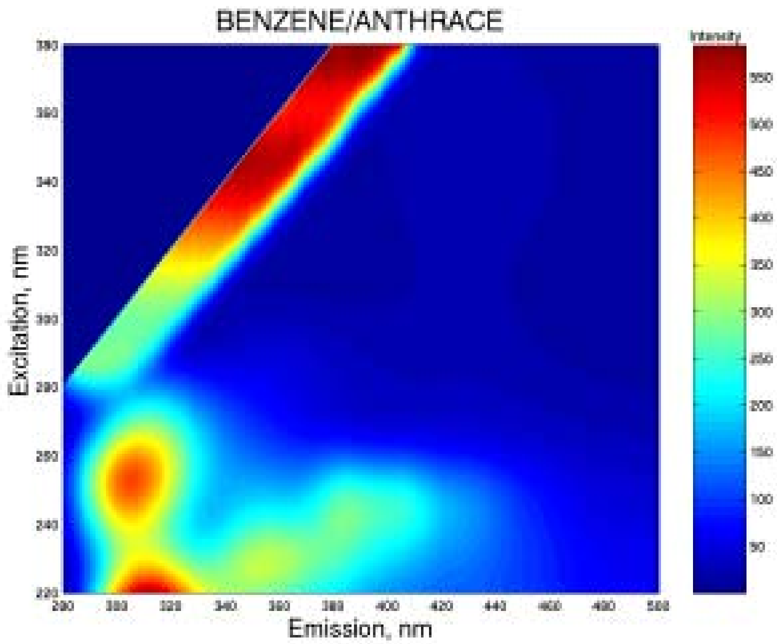
On-line Fluorescence Detection System
Evaluation of Possibilities

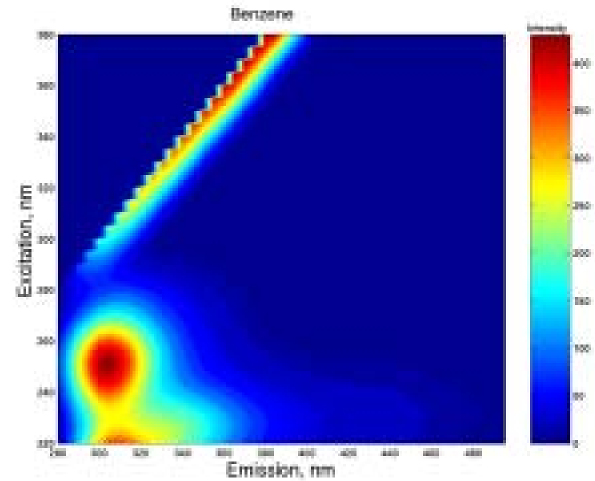
- Stellarnet fiber-coupled Spectrometer

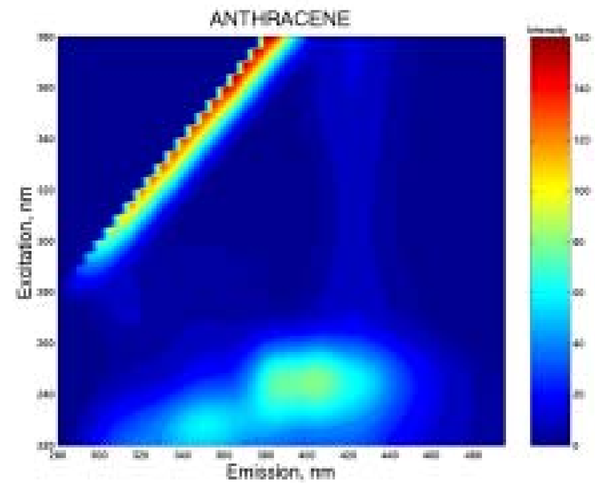
- Agilent inline HPLC Fluorescence detector

- Fluoromax 3 Stand alone fluorescence spectrometer

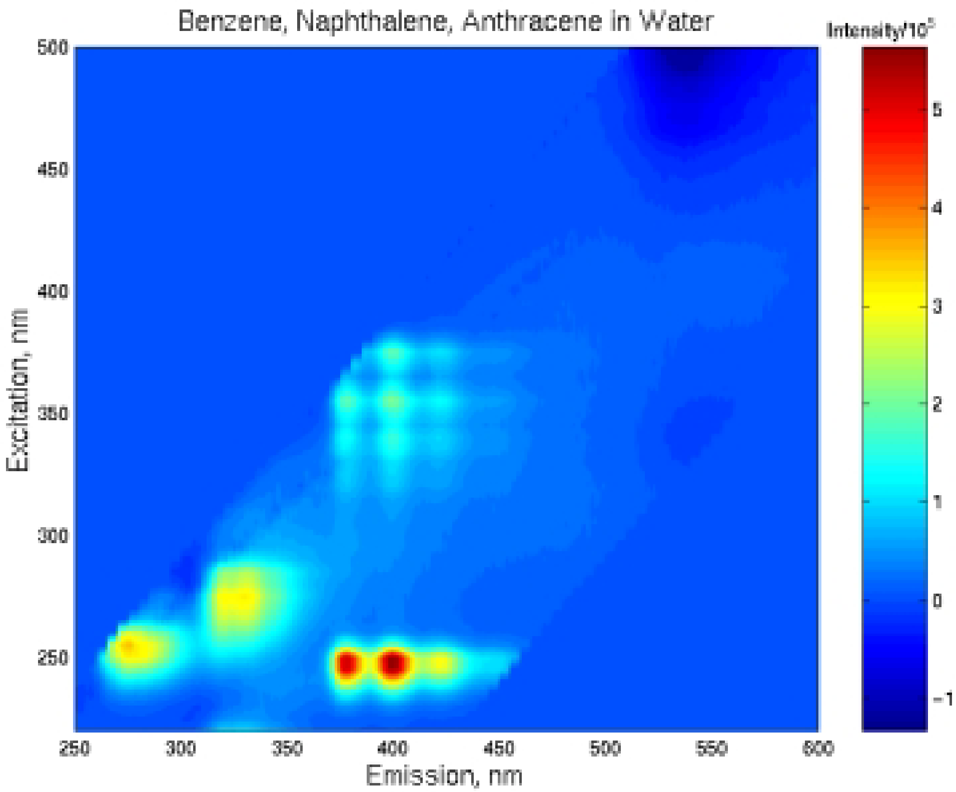
Initial Offline Fluorescent Probe Measurements (Agilent FLD)

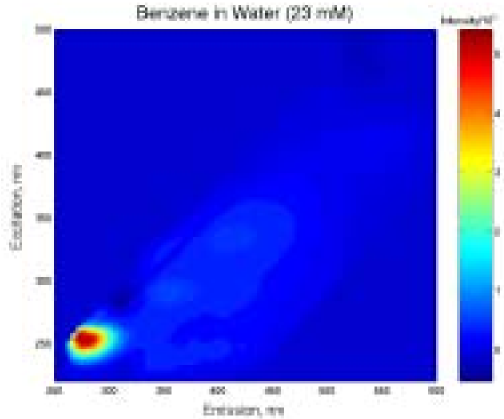


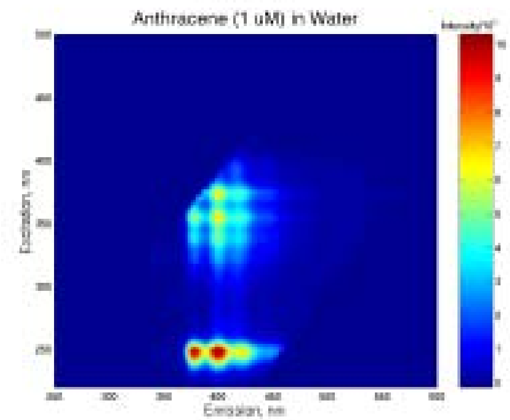


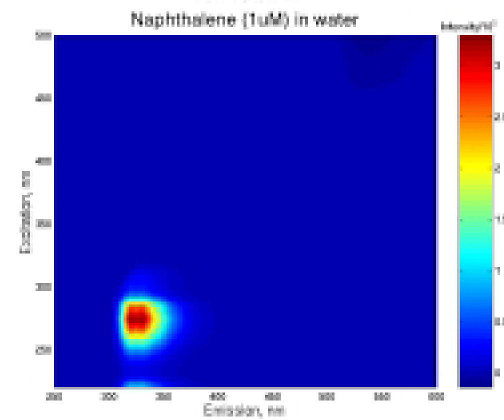


Initial Offline Fluorescent Probe Measurements (Fluoromax)

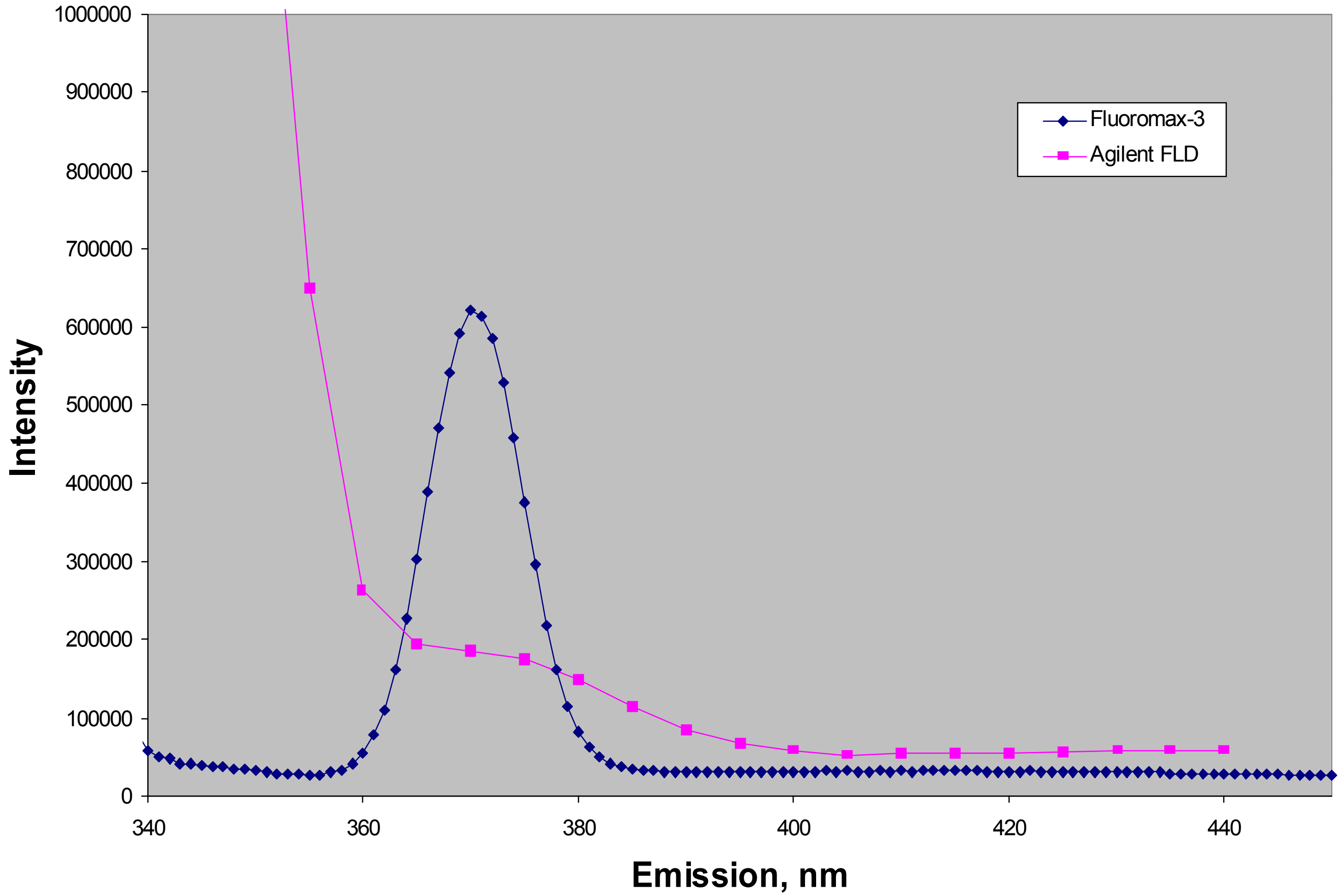








Water Raman, 330 nm Excitation



Optical Fiber Cell Coupling

Single Fiber isn't sensitive enough

Alternatives:

- Fiber Bundles
- Much brighter light source (OPO laser)

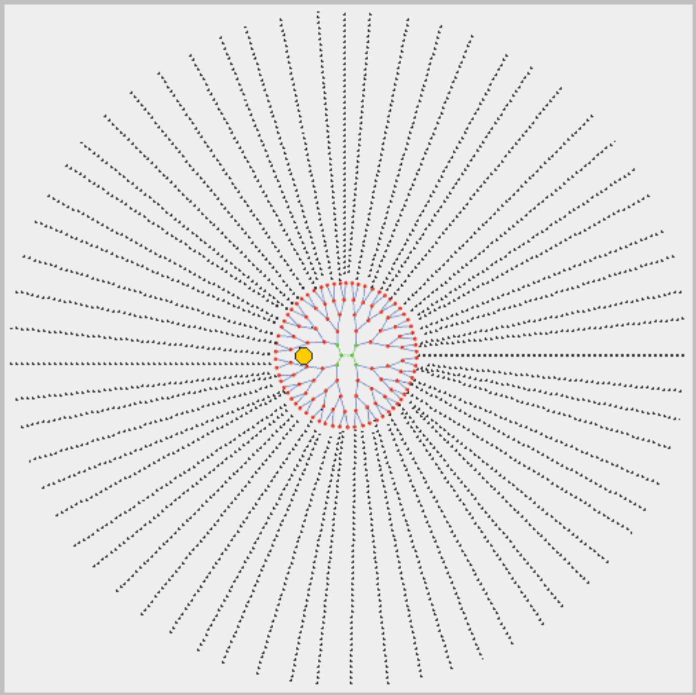
2x16 Fiber Bundle Multiplexer from Equitech is on order

Test Fluid Delivery System

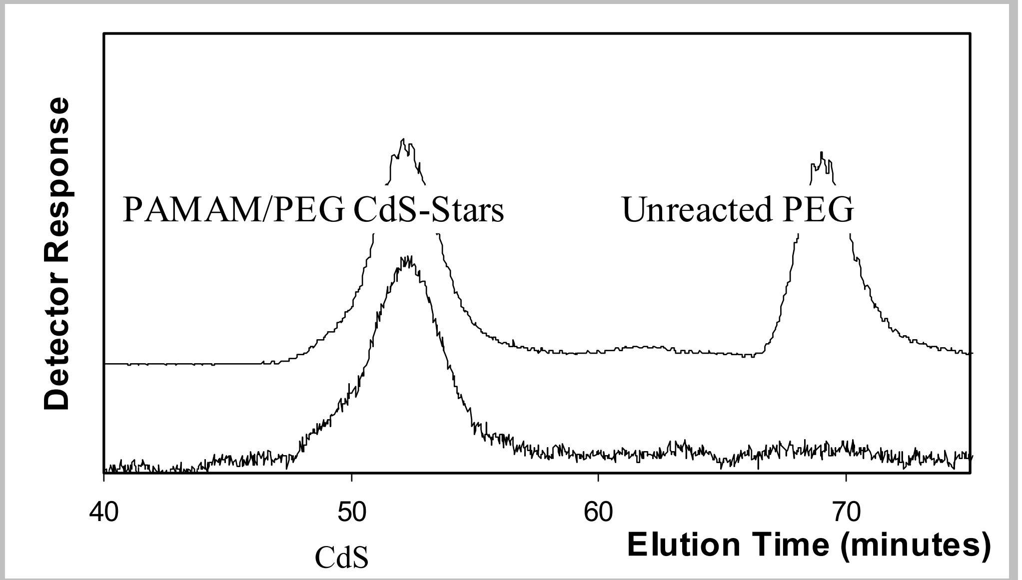
- Solvent flow controlled by HPLC pumps with inline solenoid valves
- Test fluid delivery will be handled by an HPLC type robotic injection system

Molecular Probes

CdS Nanocrystals as Fluorescent Labels



Stars containing blue-emitting CdS particles of 2-3 nm diameter have been prepared and characterized.



Structural Confirmation by GPC

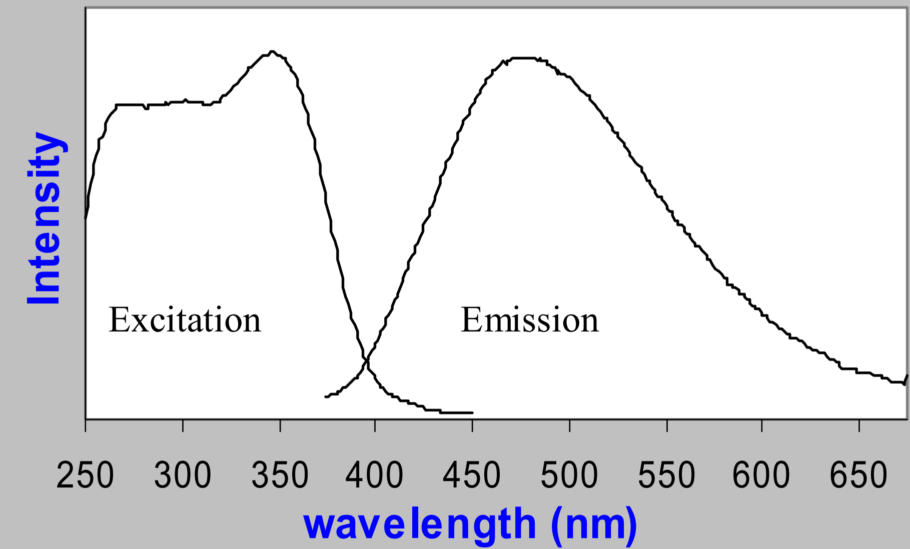
Mass Evaporative detector →

UV (360 nm) detector →

Optical Properties of CdS-Labeled Stars

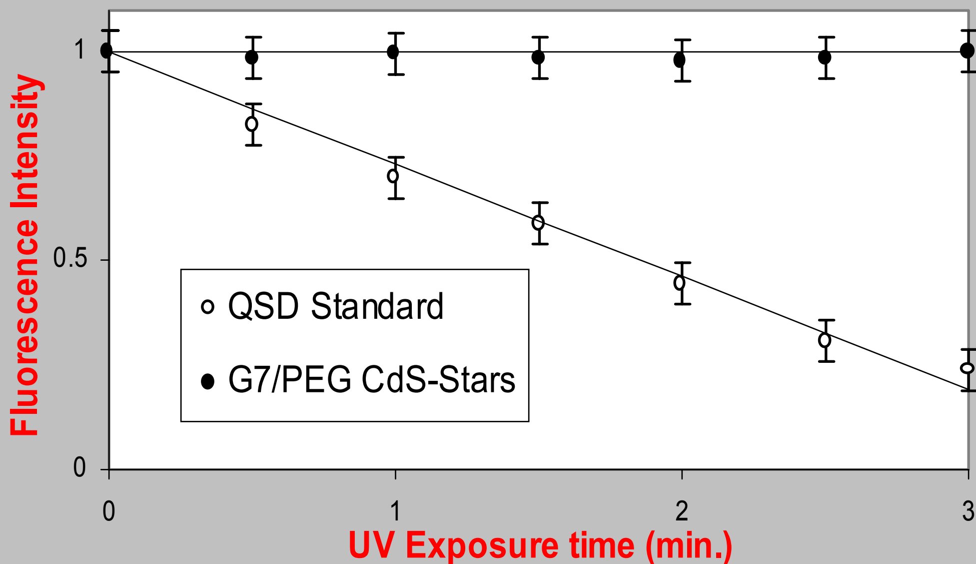
Fluorescence Spectra

Emission spectra from the CdS nanoparticles were broad, probably indicating a distribution of particle sizes and/or shapes. Excitation spectra suggested that light absorbed by the dendrimers may be transferred to the CdS nanoparticles and emitted as lower energy radiation.

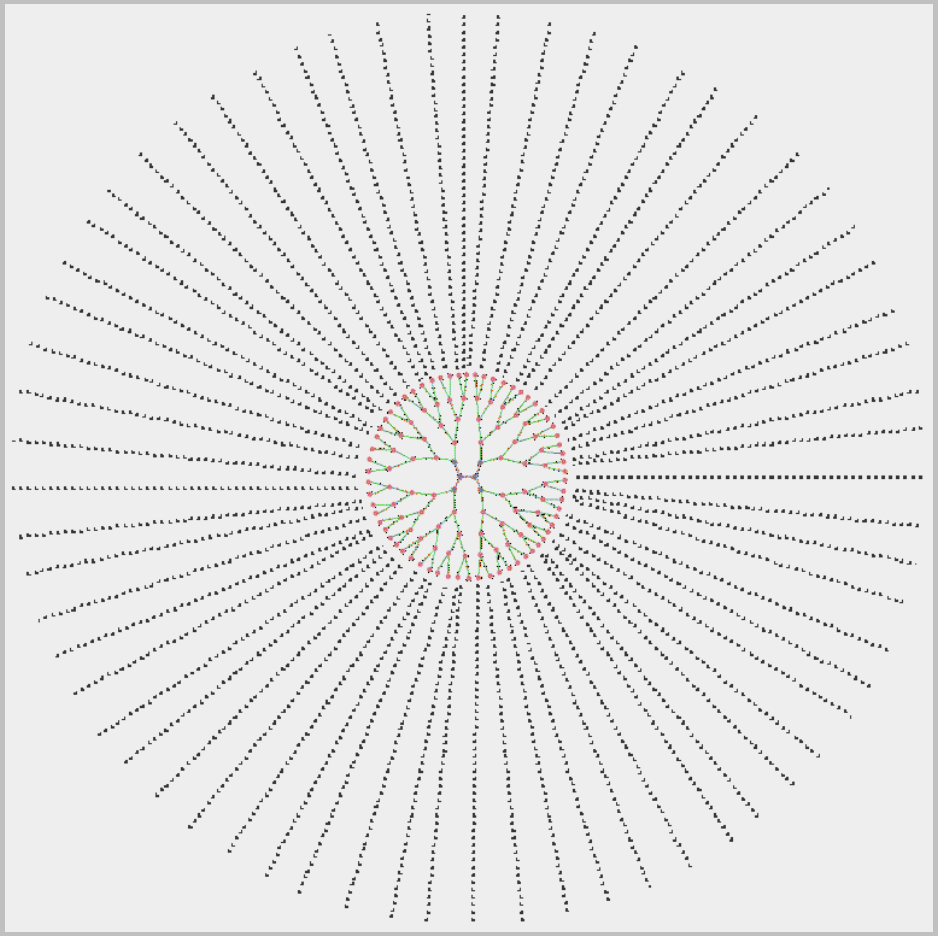


Photobleaching Test

CdS-Stars and a NIST Fluorescence Standard (quinine sulfate dihydrate) were exposed to high-intensity broadband UV radiation. The CdS nanocrystals exhibit remarkable photostability.



Polyethylene Glycol Star Polymers with Poly(amidoamine) Dendrimer Cores

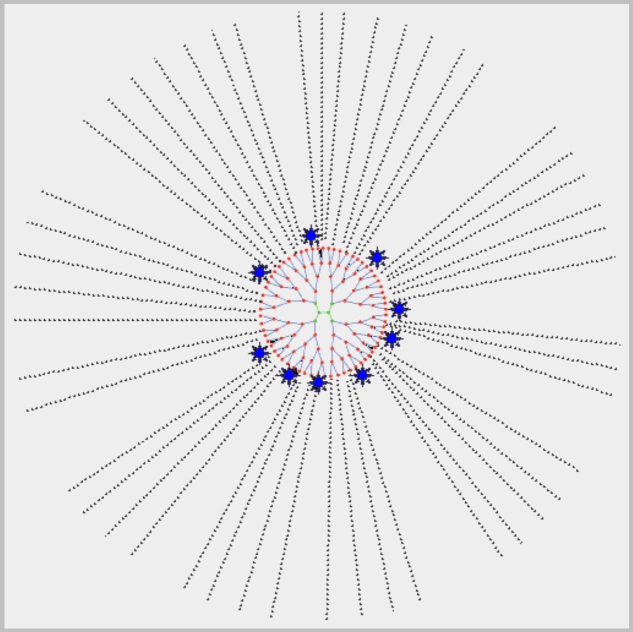


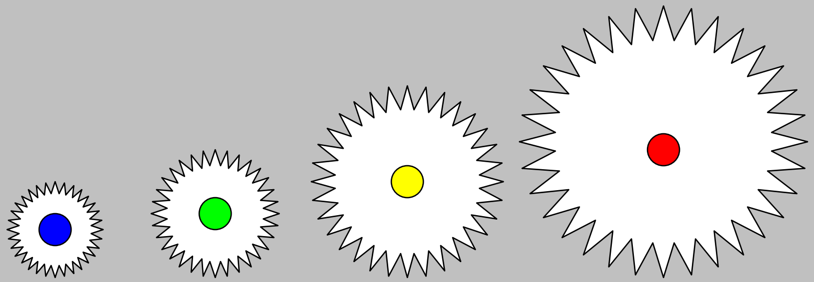
- Effective diameters 25-75 nm
- Narrow size distribution
- Versatile Solubility
- Functional Cores
- Biocompatible PEG

Probe Structures of….

- Membranes
- Polymer Blends
- Nanoporous structures
- Biomaterials

Fluorescent Dye-Labeled Dendrimer/PEG Stars: Probes for Combinatorial Characterization of Mass Transport in Membranes





Goal: a series of stars of different diameters between 10-100 nm, each with a different emission color.

- Easy purification by prep. gpc
- Size-tunable through arm M.W.
- Stable in water
- AlexaFluor™ organic dyes
  - -Readily color-tunable
  - -Narrow emissions

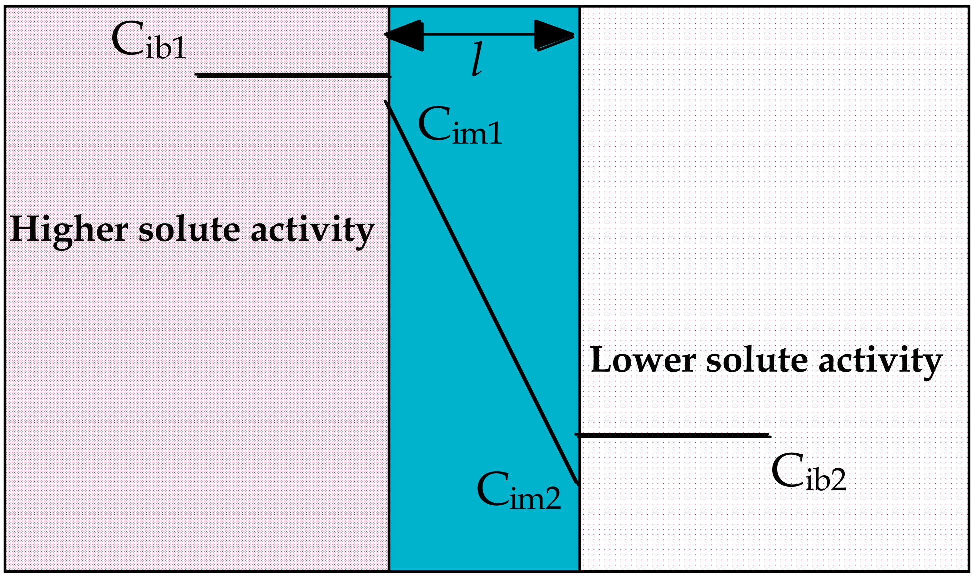
Project Status

Synthesized blue-emitting stars with effective diameter 26 nm. Membrane diffusion experiments are in progress at NIST-Boulder.

Data Analysis and QSPR Development

Simplified View of Transport

Isothermal diffusion of species "i" under its concentration (activity) gradient



Unsteady Permeation

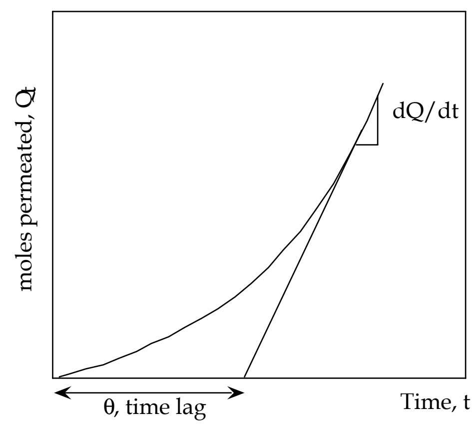
$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial z^2}$$

at t=0,	all z:	$C_{im} = C_{imo}$
at z=0,	all t:	$C_i = C_{im1}$
at z=l,	all t:	$C_i = C_{im2}$

$$C_{im1} = k_{im} C_{ib1}$$

$$Q_{it} = \int_0^t -D\left(\frac{\partial C}{\partial z}\right)_{z=l} dt$$

$$Q_{it} = D_{im}(C_{im1} - C_{im2})\frac{t}{l}$$
$$+ \frac{2l}{\pi^2}\sum_{n=1}^{\infty}\frac{C_{im1}\cos(n\pi) - C_{im2}}{n^2}\left\{1 - \exp(-D_{im} n^2 \pi^2 t / l^2)\right\}$$
$$+ \frac{4C_{im0} l}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2}\left\{1 - \exp(-D_{im}(2n+1)^2 \pi^2 t / l^2)\right\}$$



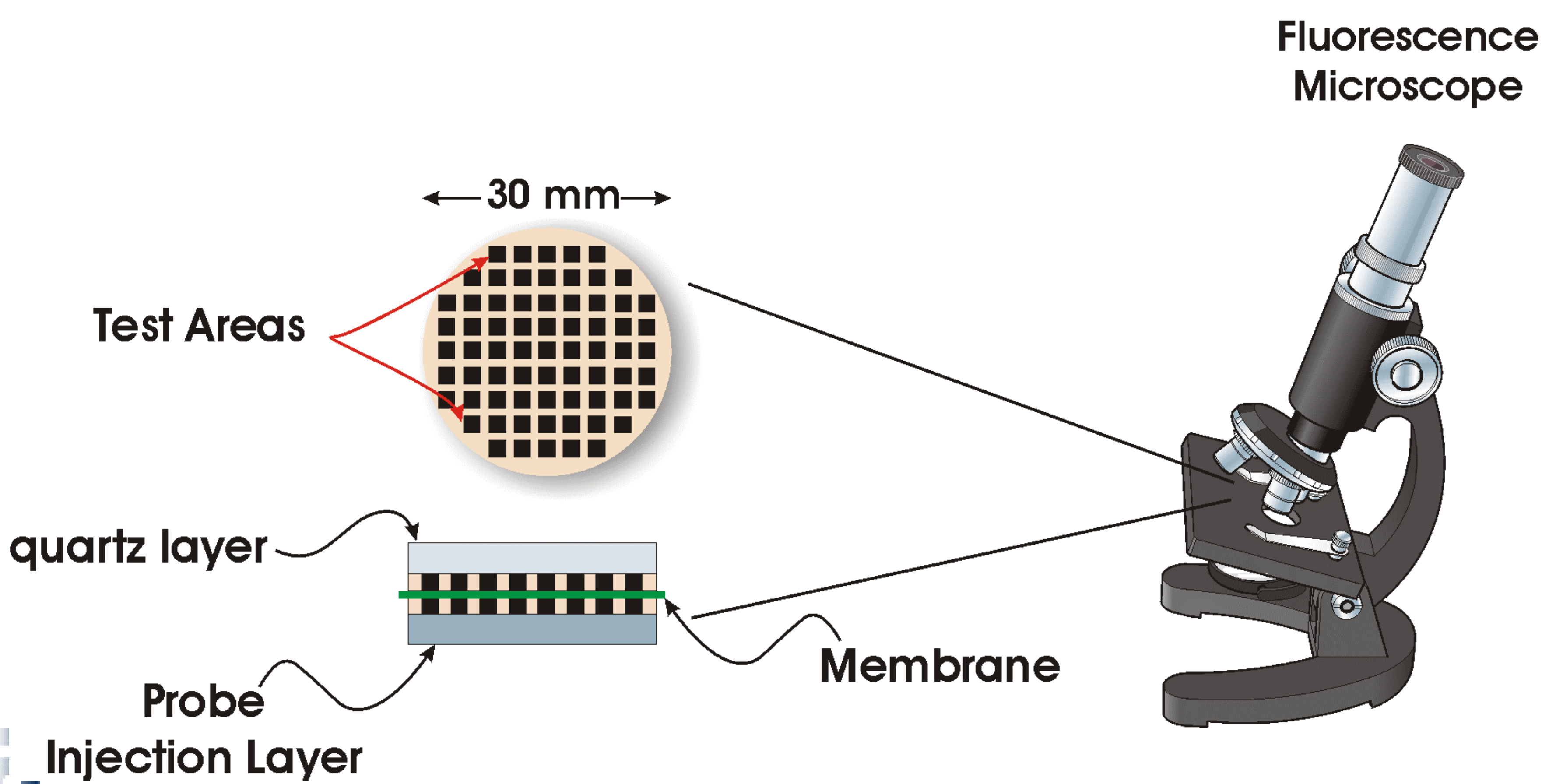
MODELING (QSPR)

- Transport Measurement
- D_{ims}'s and k_{ims}'s
- diffusion and solubility parameters of species 'i' in the film/membranes in the presence of solvent 's' and other components 1 to N

For example, use solute and solvent descriptors:

- excess index of refraction, R_2
- dipolarity/polarizability, ${}^{H}\pi_2$
- effective H-bond acidity, ${}^{H}\alpha_2$
- effective H-bond basicity, ${}^{H}\beta_2$
- intrinsic volume, V_2

Alternative Experimental Design

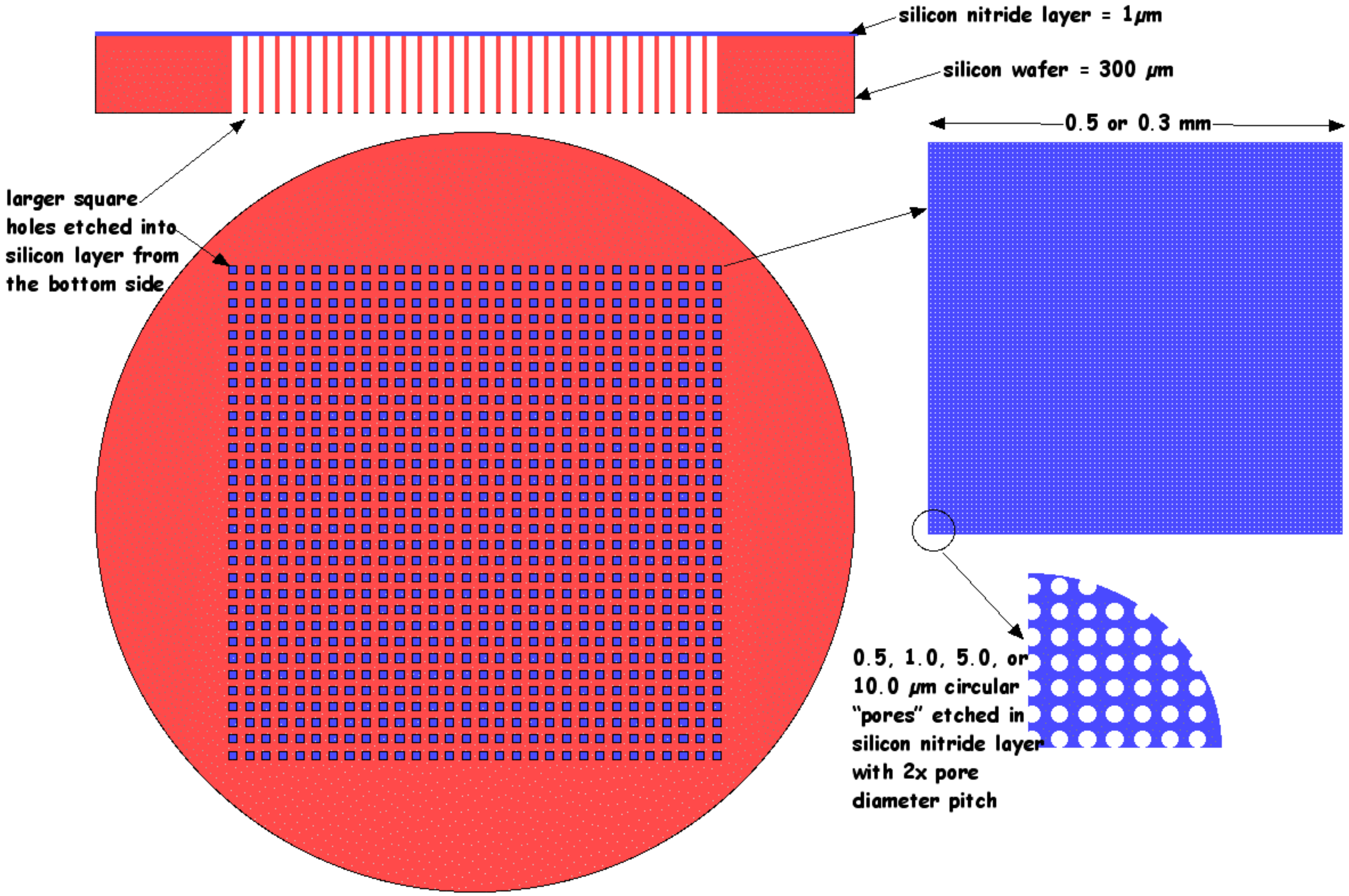


Standard Membrane Development

Two part problem

- Produce a well defined standard membrane
- Characterize the pore size distribution of the standard using traceable methods

Standard Membrane (1)



Standard Membrane (2)

- Self-Organized Anodic Alumina
- Well-defined, densely packed pores from 20-300nm
- Early development

Other Contributors

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John Pellegrino, contractor